Representation of problems during the conceptual design: A roadmap from functional to physical domains

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REPRESENTATION OF PROBLEMS DURING THE CONCEPTUAL DESIGN: A ROADMAP FROM FUNCTIONAL TO PHYSICAL DOMAINS

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Abstract: Considering that the representation of problems is a key step in the design of new technical systems, we propose a model of representation of problems. By integrating the problem solving between the functional modelling and the physical specification of the future system, we present a model enabling to build a bridge between these two domains.

We will present in this article the model of representation of problems and the heuristics we use to instantiate this model. The use of one the heuristic will be illustrate by a study case.

Keywords: Conceptual design, inventive problems, TRIZ, problem modelling, problem solving.

Introduction

The design of new technical systems is a key stake of enterprises facing a market more and more complex and competitive. To increase the efficiency of the development of new products several methods exist. These methods have been largely and successfully diffused but there still remain a critical point, the step of conceptual solutions proposal during inventive design.

To increase the efficiency of this step we develop a model of representation of the problems to be solved and heuristics to collect the data to fill in the model. We will present in this article the conceptual design viewed through the angle of problems resolution. Then we will describe the model we propose to represent the problems of design of technical systems. At least we will explain the methods of capitalisation of information to instantiate the model we developed as heuristics and illustrate their use by an example.

Solution concepts formulation, a stake of the design process

Description of the design process

The design of a new technical system is the proposal of a product answering some expectations of the market. This answer corresponds to the transition from a problematic situation to the materialisation of a product solving this problematic situation. A problematic situation is an existing situation in which dissatisfaction exists that one wishes to make evolve and for which no satisfying evolving way is known. In case of the design of technical systems this dissatisfaction is the expression of a function to realize.

The design process is commonly described as the way through four domains (Suh 1990) as illustrated on figure 1:

- The customer domain
- The functional domain
- The physical domain
- The process domain.

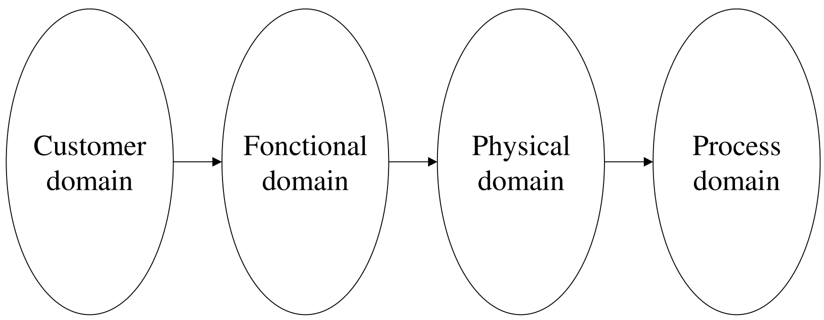

Figure 1. The design process as a way through four domains

The different existing methods (Cavallucci *et al.* 2000, Hauser and Clausing 1988, Miles 1972, Pahl and Beitz 1996) present a quite complete toolbox to transit from the domain of customer expectations to the functional domain. This process of formalisation of the expected functions is quite well controlled. In the same way numerous studies enable the facilitation of the transition from physical domain to the domain of the process of conception (Edwards 2002, Kuo *et al.* 2001). But it remains a critical point, the passage from functional domain to the physical one. This passage, which corresponds to the identification of elements enabling the realisation of expected functions, is delicate and is principally based on the competences of synthesis of the designer.

This synthesis step could be assisted by knowledge bases of solutions, but then the main difficulty is the optimal exploration of this existing base. The problem is even more complex for inventive design, as in inventive design the space of solution search is not known and then the use of knowledge bases is not efficient.

In order to improve this key transition we propose the use of an intermediary domain between the functional and the physical ones: the problem domain.

Problem domain as an intermediary step

We propose to simplify the transition from the functional domain to the physical one by adding an intermediary step, which is the problem domain. In fact this domain is the one by which any designer proceeds when solving a problem. And the identification of a physical element realising a function is the resolution of a problem. This step is a systematic one, in order to be efficient the problem domain as to be a bridge between the two other domains, it has then to be based both on functions and on physical elements of design, as shown in figure 2.

We propose a model of representation of the problems based on the study of Altshuller (1988). Altshuller showed that any problem is the result of the opposition between a wish of evolution and a specific condition of the problem linked to the environment in which the system has to proceed.

We admit, it is one the premise of TRIZ, that such a contradiction could be reformulated and point on a unique parameter that has to take two different values to solve the problem. The interest of this level of formulation is to increase the easiness of the resolution by a facilitated resort to the use of analogies.

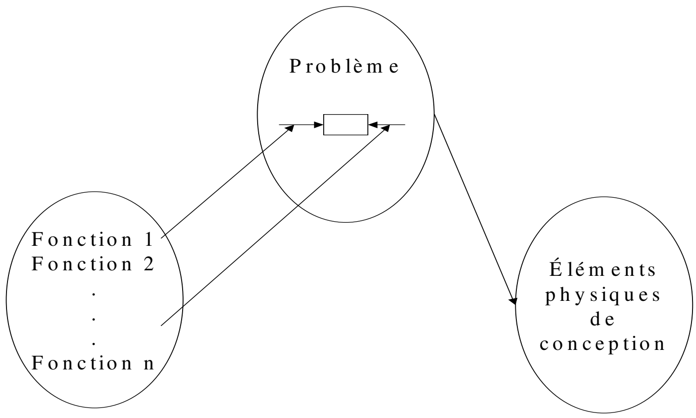

Figure 2. The problem domain as a bridge between the functional and the physical ones

The problem solving is the identification of a physical element that enables the realisation of two contradictory functions. In this way the problem domain is an intermediary space between the two previous domains.

Making the design process convergent

The way we use to guide the design process of technical systems lead to a convergent process. Indeed we propose a way of resolution of the problems that restricts the area of solution space. Our aim is not to find an exhaustive list of potential solutions, for which a long process of selection is needed, but to rapidly obtain a viable solution.

To reach this goal our purpose is to intensively exploit the partial solutions. As soon as a concept of solution is proposed it is necessary to understand which part of this concept is good as solution and which part, if it is, disable the use of this concept as solution. The measurement of this gap between the proposed concept of solution and the final solution brings more information on the problem and help in restricting the area of research of the solution.

Problem description ontology

We will describe in this section the model we use the represent the problems. First we will introduce the need for a model and the way we built our one, then we will define the concepts inherent to our model and in the last part we will present the model.

The need for a model

We propose to observe the design through the processes governing the act of resolution of problems. This approach raises the question of what is really a problem of design, which are the characteristics of such a problem and which are the parameters allowing its resolution. Simon (1987) explained that a clearly understood problem is a solved one, then the way to represent the problem is major fact of the resolution.

This description can be based on the common engineering methods that draw up an exhaustive list of the parameters, which have to be taken into account. Contradiction has an acknowledged dialectical interest and can be an interesting way of clarification of the problems. Contradiction, as Chosson (1975) pointed it out, is the representation in an explicit shape of the problematic situation, it is a clear model of what one has to solve.

To make a system evolve it is necessary to begin by modelling it, it is exactly the same for a problematic situation. In order to understand what the model of the problematic situation must include (Ross 1985), it is essential to define the objective of this model:

"The model representing a problematic situation must enable the identification of the parameter for which an evolution modifies the given situation by carrying out the expected objectives"

From this definition, we have to precise several points. First of all the concept of objectives, we hear here not only the aim set by the modification but also the non-degradation of the existing situation. No any improvement could be useful if in addition the system is elsewhere degraded. It is a strong choice that we made in regards of the concept of increasing the ideality as it is defined in TRIZ (Savransky 2000).

Then we affirm that any problem can be reduced to the modification of one of the parameters of the system, this can be confusing and requires that we explain our point of view. This assertion is checked easily for simple problems but for complex ones, implying a significant number of components, a problematic situation will emphasize a whole of problems to be solved, which we call a network of problems, because these problems cannot will be inter-dependent. For each one of these problems it is then possible to build the description according to one parameter of the system that has to be changed. The evolution of the initial situation will pass then by the resolution of whole or part of this network of problems.

Concepts inherent to the model

As our model is the result of the study of several methods, each having its own vocabulary, it is necessary to clearly define the concepts we use. As the aim of our model is to propose a bridge from the functional to the physical domains, it has to use, as interfaces, elements from these domains.

The concepts coming from the functional domain are two kinds of functions. As it is present in the functional analysis (Duchamp 1988), it seems important for us to distinguish the origin of the functions. But first we have to precise what is a function, in our model. We consider that a function is the modification of the value of a parameter. Of course the representation could be variable, but the root of a function is the one we defined. For example if we consider the function: "to light up a room", it could be described as the modification of the value of the parameter "lighting" of the room. The two kinds of function we use are:

- The use function, which corresponds to a wish of a realisation
- The constraint function, which corresponds to a need due to the environment in which the system will be.

The concept making the link with the physical domain is the solution element. This is the physical element that will realise the considered use function in regard of the constraint function.

It remains to describe the elements constituting the model. These elements are the information that is important to capitalize in order to quickly pass from the functional to the physical domains. This is the information that is useful to build a good description of the problem and to solve it by analogy.

The main concept is the one of contradiction, it is the way we represent the problems and we consider two level of formalisation of the contradiction: the functional and the physical ones. The functional contradiction is the opposition between two contradictions as the physical level consists on a contradiction on a parameter. Then we have got to introduce the definition of the term "parameter". The parameter is the root of the problem; it is the requirement on which two different values are needed.

The two following concepts are those of description of the systematic problem through the dimensions of time and space; there are the operating time (the time when the problem occurs) and the operating zone (the space where the problem occurs) as it is defined in ARIZ.

At least we have got the partial solutions, those are the concepts that could potentially be a solution but which do not fit exactly the requirements of the problem; but they bring useful information on the way to the solution.

Description of the model

The model we use to represent the process of resolution of the problems during the design of technical systems is formed of two equations:

(1) $sp = p(v_1,t_1,l_1).f_1 + p(v_2,t_2,l_2).f_2$

(2) $e = sp.\overline{\delta}$

where:

sp: partial solution
p: parameter
v_i: value of the side i of the contradiction
t_i: time of the side i of the contradiction
l_i: spatial zone of the side i of the contradiction
f_i: function of the side f of the contradiction
δ: gap between the partial solution and the final solution
e: physical element, it the final solution

The meaning of the first equation is that a partial solution is the answer for at least one of the side of the contradiction. To be a partial solution it has to perform the function by the parameter with a certain value during the needed time and at the needed place. Then the difference between a partial solution and the physical element is represented by δ. The partial solution is the final solution if δ is null.

Proposal of heuristics

About the utility of heuristics

In order to collect the information to instantiate the model we built heuristics enabling to guide the capitalisation in the way we defined the concepts. If we propose the model without these heuristics the goal of the model could seem fuzzy. Giving the previous definitions and asking to collect the information to instantiate the model is not an efficient way. It is necessary to propose a method of capitalisation to make the links between the different concepts clear and understandable.

Our purpose is to be sure that the process is well performed. The heuristics are built as questionnaires; it enables a quick collect of the information. It is one of the benefits of the use of heuristics, to increase efficiency and time of execution of the capitalisation of the data.

The last point we wanted to develop by the construction of the heuristics is to propose a pedagogical tool. The use of the heuristics, by giving the opportunity to formalize the process of problem formulation used by the designer, enables a good capitalisation of experience and a feedback of what has been useful or what was source of errors.

The heuristics are mainly based on the method ARIZ, which is an algorithm of formulation of problems of TRIZ described by Altshuller (1999). The main default of ARIZ is the level of expertise it requires to well use the method. This requirement is due to a low level of formalisation, as the different concepts used in it are not explicit enough.

To solve this problem the TRIZ experts add many comments at each step of the algorithm (Khomenko 2001) but it increases the time of application of the algorithm. The way we propose to increase the efficiency of such a methodology is the increasing of its dynamism. By the proposal of several well-formalised heuristics in place of one global algorithm, we are able to detail more the steps without increasing the number of steps of the heuristics. As the user won't be interested by a long questionnaire it is necessary to propose short ones, several if necessary, with a clear understanding of the process of formulation.

Example of construction of the model of problem by the use of a heuristic

We will present one of the heuristics of construction of the model of problem in order to illustrate our matter. We will take one general heuristic that enables the identification of the contradiction. The problem we consider is the one of hand welding machine. The problematic situation is the following one: it is desired to decrease the heat of the handle when the user is welding.

1. Question: "Describe the function for which the system was conceived."
   Answer: To weld two parts by addition of material.
   Model: f_1 = to weld two parts by addition of material
2. Q.: "List briefly the components of this system."
   A.: Point, handle, resistance, connector, cable
   M.: sp = point + handle + resistance + connector + cable
3. Q.: "Briefly give a list of the various resources of this system."
   A.: Air, lead, part 1, part 2, user
   M.: sp = sp + air + lead + part 1+ part 2+ user
4. Q.: "What is the effect which occurs and you would like to eliminate?"
   A.: The overheat of the handle
   M.: f_2 = the overheat of the handle
5. Q.: "We will call this effect the Harmful Effect."
6. Q.: "What is the effect that must be preserved during the resolution of the problem?"
   A.: The precision of the welding
   M.: f_1 = the precision of the welding
7. Q.: "We will call this effect the Positive Effect."
8. Q.: "We will now determine the parameter of influence."
9. Q.: "What is the parameter of the system for which a variation makes it possible to reduce the Harmful Effect?"
   A.: The length of handle
   M.: p = the length of handle
10. Q.: "What is the state of this parameter for which the Harmful Effect is present?"
   A.: Short
   M.: v_1 = short
11. Q.: "If # *The length of handle* # is # *Short* # then there are # *The overheat of the handle* # but # *The precision of the welding* # is preserve, is it exact?"
   A.: Yes
12. Q.: "If # *The length of handle* # is contrary to # *Short* # then # *The overheat of the handle* # disappear, but # *The precision of the welding* # remains, is it exact? "
   A.: Yes

The modeled problem is then:

(air + lead + part 1+ part 2+ user + point + handle + resistance + connector + cable) = length of handle(short).precision of welding + length of handle(long).overheat of handle

Then the partial solutions have to be tested as elements to solve the problem. The first partial solutions we proposed are the elements already available in the system, as they do not increase the complexity or cost of the system.

This contradiction has been solved by using one of the fundamental resources: the air. To avoid overheat we need a good thermal isolation, and air provide it. The handle has then been modified in order to have a long length to provide a good thermal isolation but a short distance to assume precision (as shown on figure 3).

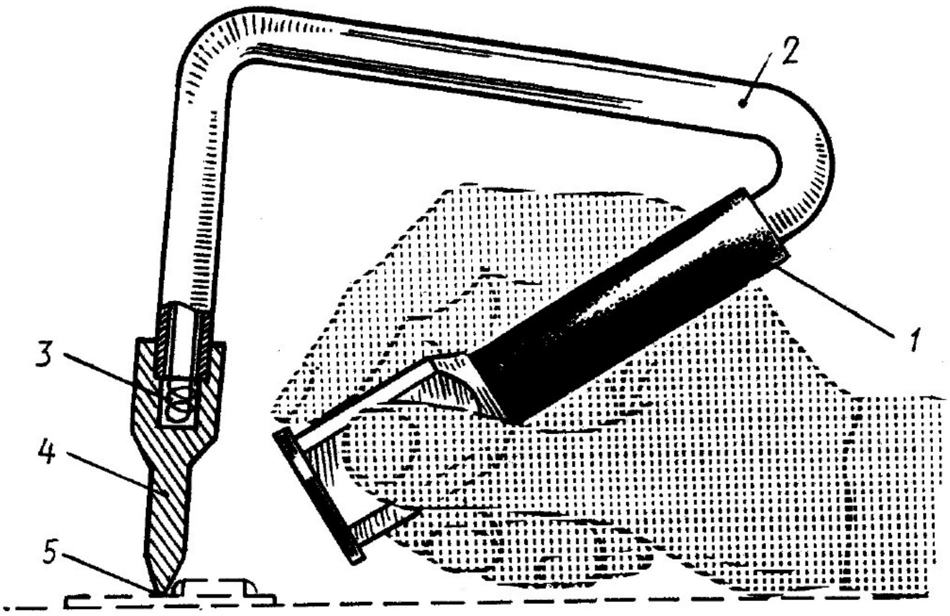

Figure 3. Use of air as thermal isolation

This is a quite simple example, which is similar to simple problems whose initial problematic situation is relatively clear, otherwise it is necessary to capitalize the various elements in a progressive and iterative way. We provide phases of validation of the capitalized elements to check the reliability of the build model. These phases enable the user to stop the way he is formulating the problem, and bring him a better comprehension of the problem, and of the way the problem is modelled.

Conclusion

We focused our approach on the conceptual design, because we think that it is one of the critical point in the inventive design. To increase the efficiency of this step we developed a model of representation of the problems met during the design of technical systems. The need for such a model is the fact that we have to clearly understand what has to be done before doing anything.

But having a model if we do not know how to use it is not efficient. That is why we developed user-friendly heuristics, those heuristics being computerized in order to facilitate their implementation. The method is a guide used to iteratively travel between the two domains of the technical and physical domains.

We today feel that such an approach has to be widely develop and generalise, if one understand clearly how to formulate problem and which parameter of the system is the root of the problem, it will be easier for him to use the traditional methods of design, and he will do this more efficiently, whatever the method is. So our proposal is compatible with what already exist to control the design process, it can be used at each stage of the process as soon as a problematic situation appears.

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